A conceptual LUTI model based on neural networks

F. Tillema & M. F. A. M. van Maarseveen
Centre for Transport Studies, Civil Engineering, University of Twente, The Netherlands

Abstract

This paper deals with Land-use-Transport-Interaction *(LUTI)* and presents a conceptual model of a data driven LUTI modelling tool based on neural networks. A starting point is the general opinion of experts on the state of the art LUTI models; currently used land use transportation models are too aggregate in substance. Therefore to enhance the interaction between transport and land-use, researchers propose the refinement of the models; internalising more comprehensive relationships. However, the lack of a good theoretical framework impedes the development and consequently the use of these models on a large scale. This fact has fuelled questions: (i) does *transport planning* need these comprehensive descriptions of land use; (ii) is it necessary to disaggregate and refine the models further in order to be able to do consistent transport planning; (iii) which land use characteristics should at least be internalised; and (iv) which modelling method is suitable for implementation.

Based on literature, the hypothesis is that the first question can be answered by 'no' and no further refinements are needed. Literature shows that the main drivers for land-use changes are the location choice of both households and firms. Therefore only these two building blocks are used in relation with the transport component. Artificial neural networks *(ANNs)* will be used as the modelling technique. *ANNs* are data driven techniques that find relationships in data during an auto calibration process. Therefore *ANNs* can work without having a sound theoretical framework. This characteristic offers possibilities for LUTI modelling that lacks a sound theoretical framework. The research leads to a conceptual model. A literature review shows that the individual building blocks of the conceptual LUTI model can be modelled using neural networks. However, an integration of the building blocks has not been established yet. Further research has to result in the actual implementation of the proposed model.
Keywords: land use, transport, LUTI, neural network, planning.

1   Introduction

This paper deals with Land-use – Transport - interaction *(LUTI)* and presents the conceptual design of a LUTI modelling tool based on *empirical data*. LUTI models help to improve forecasting of land-use transport developments, by extending *traditional transport planning* with a land-use component. Internalising these land use transport interactions in traditional transport planning makes planning consistent; land use interacts with transport and vice versa. Clearly, most transport planning tools comprehend only a one-way relationship between land use and transport and therefore lack this consistency. The dynamic interaction between land use and transport determines on a strategic level the autonomous development of transport and land use systems.

Transport planning is the necessary discipline that provides systematic techniques to understand, maintain and forecast the traffic and transportation system. Not only does the design and performance of a transportation system provide opportunities for mobility, but also over the long term it influences patterns of growth and the level of economic activity through the accessibility it provides. After all, a transport system is a basic component of an area's social, economic, and physical structure. Besides transport, land-use also determines the opportunities for mobility. The interaction between land-use and transport is a widely accepted but still not generally understood topic. Therefore, as a logical step, traditional transport planning has not yet embraced the land-use topic.

The concept of land-use transport interaction adds a new aspect to the relationship between supply and demand. LUTI models view demand as a combined and integrated function of both quantities, i.e. traffic flows, and characteristics of the environment, the land use. So, demand is not only influenced by user-behaviour and personal characteristics. The demand is also strongly influenced by the changing environment caused by the interaction between land use and the transport system; in LUTI terms called a *feedback link*. The channel tunnel between France and the U.K. is a leading example of how the supply of infrastructure has an impact on the demand for travel. And as a consequence, the demand influences the regional development, the land use factor (Dundon-Smith and Gibb [1]). Another large-scale example is the development of the Öresund Bridge between Denmark and Sweden. The effects of the bridge are to a large extent comparable with the channel tunnel.

Internalising the feedback link distinguishes LUTI models from normal transport planning models. The term interaction implies therefore a (dynamic) feedback mechanism. The land use model supplies the transportation model with estimates of the location and volume of travel generators. This involves the demand for employment, residential, shopping and other activities at different sites and translating these demands into quantitative variables as the total amount of trips generated. Land use is a general term here, covering both the types and intensities of activities (demand) taking place at specific urban sites as well as the physical area of land and any built structures used in support of such activities. The transport system supplies the land-use system with estimates of the accessibility. The notion of locational *accessibility* plays a central role in all

currently operational models. As an integral component of such accessibility, travel cost changes, or generalised costs, become part of the mechanism used to reallocate labour, residents, retail and other activities.

The state of the art in integrated land use transport modelling is to view both transport and land-use as important variables. Therefore, as a consequence LUTI models internalise both transport *and* land use in great detail. The fine level of detail makes the scope of the currently used LUTI models broader than consistent *transport planning* alone. To enhance the interaction between both transport, land-use and activity components of the model, research is done into more refinement of the links between demand and supply; internalising more detailed relationships into the models. In general, this results in more comprehensive models that are still not operational on a large scale, partly due to the increasing data needs. In addition, researchers still believe that current land use transportation models are too aggregate in substance, space and time to match the sophistication of contemporary activity-based travel demand models and to respond to the requirements in spatial resolution (Wegener [2] [3], Timmermans [4]).

This fact has fuelled the following questions: (i) does *transport planning* need these comprehensive descriptions of land use; (ii) is it necessary to disaggregate and refine the models further in order to be able to do consistent transport planning; (iii) which land use characteristics should at least be internalised; and (iv) which modelling method is suitable for implementation. To answer these questions it is necessary to firstly look at the current state of the art in LUTI modelling and its problems.

2   Criticism on LUTI modelling

So, the necessity of LUTI models is theoretically proven. But, the development of these models into applicable models for planning purposes is very difficult. Wegener [2] formulates the process until 1994 in the following words: 'After a period of stagnation in the development and use of integrated models, mainly triggered by Lee's "Requiem" (Lee [5] [6]), nowhere in the world have large-scale urban models become a routine tool of metropolitan plan making. If one considers the enormous range of planning problems facing a typical metropolitan area in industrialised countries today, the spectrum of problems actually addressed with current LUTI models is very narrow.' Wegener mentions the name of Lee and his requiem. Lee attacked a number of issues in his requiem:

– Black Box character of the used models: Not even the modellers could understand what was going on inside their models and that consequently they could only massage them into behaving reasonably in relation to such data as they had. There was no assurance that the models did or would behave reasonably with respect to variables for which no data were available. There was no apparent understanding of what relationships caused which results.

– General purpose: The ideal of a general purpose tool that contains a repository of knowledge relevant to the problem solving, and

accumulates more knowledge as it is improved and used, has a lot of appeal.

A second critical note was more recently published (Timmermans [4]). Timmermans states that although expected, no strong tradition in transportation and urban planning exists in developing integrated land-use models. Several transportation researchers and urban planners have developed integrated land-use transport models since the 1960's. But the field has always been one of sub-dominant interest, especially compared to the modelling of various aspects of transport demand, which typically treated land use as an exogenous variable of the model. Most early work stems from urban planning, but in that discipline, the interest has virtually disappeared completely. One needs to be a die hard to become involved in this area of research. Timmermans furthermore states that the fundamental problems identified in the 1970s still remain to be solved.

The criticism is hard. Fortunately researchers all over the world publish new insights in how to revive the discipline. The next section shows some insights.

3 Towards better LUTI models

So, the necessity of LUTI models has been stressed, but the current state of the art of LUTI modelling does not tackle important problems. What should be done before this area of research can be called mature and if that could be accomplished what should be our realistic expectations about the potential use of such models (Timmermans [4])? Two insights are proposed.

3.1 Increase in comprehensiveness

The current state of the art in integrated land-use transport models shows that the research area is far from maturity. At this moment a number of approaches to revive the topic of integrated land–use transport models are pinpointed. A general conclusion is that it seems that a simplification of the approach will be counterintuitive. However further model complexity will increase the models black-box character and data needs.

Timmermans identifies a few central issues to revive integrated land-use - transport models. The four central issues are: (i) inducing principles of spatial behaviour; (ii) developing context and domain-specific behavioural models; (iii) developing truly integrated models; (iv) to go further than only accessibility measures as explanatory variables of the residential choice; and (iv) modelling spatial planning; modelling the role of spatial planners. Timmermans [4] states that although progress has been made in terms of more detailed classifications and finer scales of spatial resolution, not much theoretical progress has been made. The demand for refining the models seems to monopolise the conversation.

3.2 Decrease in comprehensiveness

An interesting vision on comprehensive modelling is given by Lee [6]. Lee illustrates the trade-off between the time horizon of the planning decision-

making and the level of detail. Planning is broken up into three types. Strategic planning, mostly the scope of LUTI models, deals with the long term by keeping an eye on the future. According to Lee, large scale modellers often do not adequately recognize the level of detail tradeoffs between tactical and strategic, and, as a result, strive for too much inclusiveness, more like 'comprehensive' planning than is ideal for strategic planning. Modellers see complexity in the world, and conclude that failure to replicate known complexity is tolerating ignorance without cause. In short, Lee pleads for less comprehensive models when the time scale is strategic.
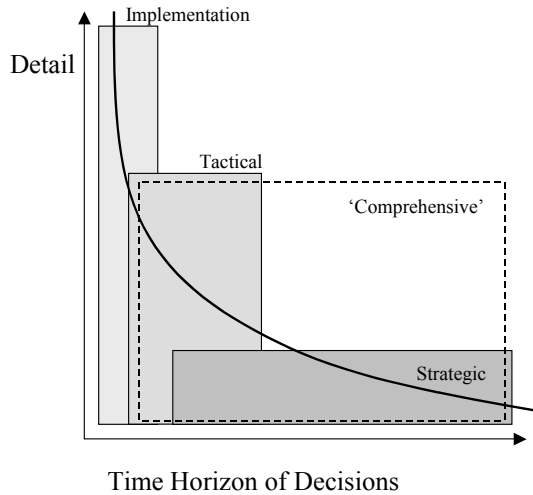

Figure 1:   Trade-offs among strategic, tactical and implementation planning (Lee [6]).

3.3 Discussion

So, the message of many experts on the interaction between land use and transportation is clear: add more detail, otherwise models will not be able to generate reasonable forecasts. However, increase in complexity results in less transparent, black box, models, which seems to be a problem in itself. But is it necessary to disaggregate and refine the models in order to be able to do consistent *transport planning* or can newly introduced computational techniques accomplish the relationship between land use and transport empirically? Lee's figure is very illustrative for the opposite approach; limiting the necessary comprehensiveness to an adequate level. But which approach is the right one? Because in this paper LUTI modelling is viewed from a strategic transportation planning perspective the approach of Lee is interesting; land use is only internalised to make transport planning consistent and adding to much detail with respect to land use guides away from the main goals of strategic planning. The answer to the question what relationships then have to be internalised lies in the definition of the necessary relationships of a transport based LUTI model.

4 Necessary relationships in LUTI modelling

One of the problems in modelling less comprehensively, is the lack of adequate knowledge and information about which land use variables to internalise for consistent planning. The question that has to be answered is which land use factors are necessary to internalise in the traditional framework of transport modelling in order to make it consistent. The transport component is clear. In general a usable output of the transport system is some accessibility measure. But how about the land use components?

Literature review comes up with the following conclusions. Human activities continuously change the land; it was recognised that human activity is the most important driver of land use changes. The term human driver is a collective term for a variety of driving forces operating at different scales (Otter [7]). It is discussed that the human drivers have both macro and micro effects. Macro drivers have no direct effect on land use change. Land use decisions take place on a micro level. Human drivers involve a strong economic component and economics in general studies 'the behaviour of mankind'. Looking at this economic perspective a number of decisions in a spatial economic setting can be made: (i) consumption decisions; (ii) travel decisions; and (iii) location decisions.

These decisions are somehow linked (Otter [7]). The consumption decision for example may depend on the location of the individual making the decisions and may also involve some degree of travelling. In the following the focus will be on location decisions. Location decisions on a micro level are important factors of land use changes on a macro level. Location decisions of both households and firms have a direct effect on land use and can help to explain changes in land use patterns. The location decision is not easily changed in the short run as was stated by Wegener [2], and provides constraints on the remaining choices. The location of an individual, after all, influences travel decisions in a spatial context.

So, location of firms and households are important factors of land use changes in a residential or industrial/commercial context. These factors therefore have to be used in defining the land use component of a LUTI model. The building blocks for a less comprehensive model than become: (i) accessibility; (ii) location choices for households; and (iii) location choices for employment.

5 Can neural networks model the necessary relationships

5.1 Why neural networks

The previous sections proposed three reasons that for making LUTI modelling less comprehensive. Firstly from the viewpoint of transport planning it was stressed that for making transport planning consistent less comprehensive descriptions of land use can be used. Secondly, when strategic modelling is a goal, the necessary comprehensiveness is less than for modelling on shorter levels. And finally, until now and despite the amount of research undertaken, no

clear and generally applicable theories have been developed. Therefore a further refinement of the models seems impossible and as a consequence theory-driven models cannot be used on a large scale. The problem of lack of theory is also a problem when modelling land use in a less comprehensive manner. To overcome this, an interesting approach based on newly introduced parallel computing techniques is introduced (Rodrigue [8]). This approach focuses more on creating relationships by using empirical data sets than on using sound theoretical frameworks. Rodrigue states that the urban structure and its evolution must not be considered as given but as the result of complex interactions. It is precisely over these aspects that most of the operational land-use transportation models are deficient. Lack of theory prevents models to become standard. He introduces the possibility of creating a self-adaptable spatial model.

The assumption is that a transportation/land use system is a parallel system. A parallel system involves that its elements are affecting each other simultaneously in time and space. Until recently, the modelling of spatial systems has strictly involved the development of sequential models that were trying to represent a system in a straightforward logic with several steps. This has a fundamental drawback since systems do not work in a sequential manner. A true parallel model is not foreseeable without a true parallel computing structure. Neural networks are mathematical models that simulate parallel information-handling features and are therefore suitable for this job.

Recent developments in parallel distributed processing have enabled geographers and regional planners with new tools and methodologies to simulate complex urban dynamics with the usage of neural networks. As a pattern and process associator, a neural network enables to transform the structural relationships between its elements and thus provides a self-adaptable, auto calibrating model. This new approach will be able to overcome a number of important deficiencies in the currently used models. The theory behind the models lies within the conceptual model. Because a neural network model is self-adaptable, the absence of clear basis of theory is less important because the model seeks its own relationships out of data; an empirical approach. However, increasing the understanding of the relationship and building theory is therefore difficult when using neural networks. This is in contrast to the traditional approach. It is difficult to make a model based on sound theories, when theories are not yet developed to a satisfying level.

These models seem to fit in Lee's framework; avoiding the trap of more detail, but using the detail in the data to get a grip on the relationships. The level of detail modelled is to a large extent influenced by the number of variables used. Data driven, empirically based, models have been proposed, but not yet developed. Despite the lack of research the empirical approach is a promising one. The use of these neural networks has been limited. Dougherty [9] gives an overview on the application of neural networks in transportation systems. A conclusion is that the use of neural networks has been very limited till so far. The usage for modelling spatial structures and processes of transportation systems using neural networks has been even more limited. However there exists research that covers the necessary relationships.

5.2 Can neural networks model the necessary relationships

Accessibility was mentioned as the transport component of a LUTI model. A number of researches have been conducted with neural networks that fall in the classical framework of transport planning. Huisken and Coffa [10], Fischer and Gopal [11], Mozolin *et al* [12] and Black [13] all give examples of how different steps in the transport planning framework can be modelled using neural networks. The main focus is on modelling the trip generation and the trip distribution. The combination of these researches can be used as a model to estimate accessibility.

The driving force behind land use changes was formulated as the location choice of both households and employment/firms. Raju *et al* [14] have the objective to model the location choice of households. Based on micro simulation combined with neural networks, the household location choice is forecasted. In a test case the combined model forecasts the location choice of households very well with a R^2 of 0.986. Other research gives an example of the application of neural networks for the forecasting of the demand for electricity. The model is based on neural networks and can be split up into two sub models. The first model is a global model in which the number of users is assigned to a specific area. This model can be seen as a location choice model. The second model assigns the electricity to the inhabitants of zones.

6   Towards a new model approach based on neural networks

This section present a conceptual model based on neural networks incorporating the necessary land use relationships. The objective of developing a new LUTI model should be in this case: 'The development and evaluation of an empirically based neural network transportation-planning model that internalises the principles of land-use transport interaction'. Pursuing this objective, the focus is placed on integrating the land use principles in a transport-planning context. As stated before, the development and evaluation of the model does not directly lead to new theories or conclusions on tested theories.

Both estimation of transportation system performance in a current and future state is regarded important, more than detailed forecasting of the land use patterns and market mechanisms. This leads to a model that internalises, transparent, less extensive land use relationships into a more traditional transport-planning model. The shortcut relationship illustrates that only the prerequisite land use variables are internalised in the model. Based on the discussion above, the conceptual model will then look like:

The figure shows the building blocks of transport and land use. In between the building block the neural networks are situated. The building blocks are defined as: (i) accessibility/interaction; (ii) population per zone: number of households in a specific area; and (iii) employment: number of employment places in a zone.
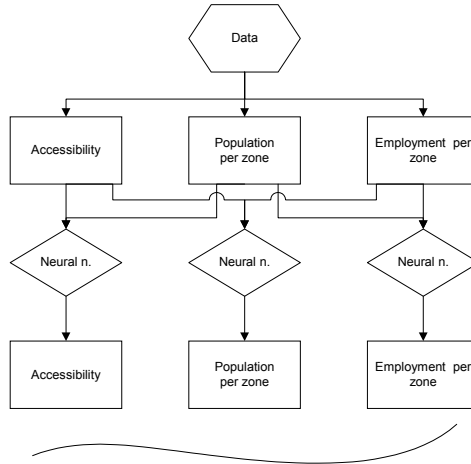
Figure 2: Conceptual model.

The exogenous data should exist of information on household characteristics, housing characteristics and finally the employment characteristics. The parallel model changes from state 1 to state 2 as a result of changes in the system, amongst others capacity changes in the availability of dwelling units/employment locations and capacity changes in the transport system.

7 Conclusions

This paper presents a conceptual LUTI model that is based on neural networks. The state of the art in LUTI modelling shows that the currently used models are not widely applicable and have to large extent theoretical drawbacks. Modelling less comprehensively was proposed as acceptable when modelling land use is done in a transport planning framework. The aim is to use a data driven approach in order to overcome the problems of very comprehensive modelling as assumed necessary. The model has to be built around at least three components; (i) accessibility; (ii) household location choice; and (iii) employment location choice. This still not overcomes the problem of the lack of theory. Data-driven, empirical models, based on neural networks are introduced as an alternative to the theoretically based models. In general, these models are not very suitable to form new theories due to the black box character of neural networks. However, when calibrated soundly, these models can make transport planning consistent and they give an insight in the influence of the relationship between land use and transport. Literature review shows that neural networks are successfully used the context of these three components. The most important aspect of future research is the implementation of the conceptual model.

References

[1]   Dundon-Smith, D.M & Gibb, R.A., The Channel Tunnel and regional economic development, *Journal of Transport Geography*, Volume 2, Issue 3, pp. 178-189, 1994.

[2]   Wegener, M., Operational Urban Models: State of the Art. *Journal of the American Institute of Planners*, 60, pp. 17-29, 1994.

[3]   Wegener, M., Current and Future Land Use Models, *in: G.A. Shunk, P.L. Bass, C.A. Weatherby and L.J. Engelke, Land use Modelling Conference Proceedings,* Texas Transportation Institute, Arlington, Texas, 1995.

[4]   Timmermans, H., The Saga of Integrated Land Use –Transport Modelling: How Many More Dreams Before We Wake Up?, *Keynote paper, 10th International Conference on Travel behaviour Research, Lucerne*, 2003.

[5]   Lee, D.B., Requiem for Large-Scale Models. *Journal of the American Institute of Planners,* Volume 39, pp. 163-178, 1973.

[6]   Lee, D.B., Retrospective on large scale urban models, *Journal of the American Planning Association,* Volume 60, No. 1, 1994.

[7]   Otter, H.S., *Complex adaptive land use systems: an interdisciplinary approach with agent-based models*, PhD thesis, 2001.

[8]   Rodrigue, J.-P., Parallel modelling and neural networks: an overview for transportation/land use systems, *Transportation Research C*, Volume 5, No. 5, pp. 259–271, 1997.

[9]   Dougherty, M., A review of neural networks applied to transport, *Transportation Research C*, Volume 3, No. 4, pp. 247 – 260, 1995.

[10]   Huisken, G. & Coffa, A., Neural Networks and Fuzzy Logic to improve Trip Generation Modelling, *Proceedings of the 9th International Association for Travel Behaviour Research Conference*, Institute of Transport Studies, IATBR, Gold Coast, Queensland, Australia, 2 – 7 July, 2000.

[11]   Fischer, M.M., & Gopal, S., Artificial Neural Networks. A new approach to Modelling Interregional Telecommunications Flows, *Journal of Regional* Science, Volume 34, No. 4, 1994.

[12]   Mozolin, M., Thill, J.C. & Lynn Usery, E.L., Rit distribution forecasting with multiplayer perceptron neural networks: A critical evaluation, *Transportation Research C*, Volume 34, No. 1, pp. 53, 2000.

[13]   Black, W.R., Spatial interaction modelling using artificial neural networks, *Journal of Transport Geography,* Vol. 3, No. 3. pp. 159-166, 1995.

[14]   Raju, K.A. Sikdar, P.K. & Dhingra, S.L., Micro-simulation of residential location choice and its variation, *Comput., Environ, and Urban Systems,* Volume 22, No. 3, pp. 203-218, 1998.